Experimental Analysis of Hot-Surface Ignition Temperature of a Dust Layer of Selected Dusts

by

Wan Alyssa Binti Wan Othman
16881

Dissertation submitted in partial fulfillment of
the requirement for the
Bachelor of Engineering (Hons)
(Chemical Engineering)

MAY 2015

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CERTIFICATION OF APPROVAL

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Approved by,

_____

(Dr. Azizul Buang)

UNIVERSITI TEKNOLOGI PETRONAS
BANDAR SERI ISKANDAR, PERAK
May 2015

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or person.

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WAN ALYSSA BINTI WAN OTHMAN

ABSTRACT

Dust explosion are one of the biggest threats in many industry where dust layer and/or cloud form during technology processes, which are capable of ignition. Chemical Safety and Hazard Investigation Board (CSB in USA) identified at least 281 dusts fire and explosion that occurred in US industrial facilities from 1980 to 2005. In this project paper, a study on experimental analysis of hot-surface ignition temperature of a dust layer of a selected flammable dust is conducted. The method used to conduct the experiment is to determine the hot-surface ignition temperature by using hot plate following the E 2021-01 ASTM Standards. Mainly, the study will focus on the non-ferrous powder dust samples. The factors considered in the study will be the types of dust and the layer thickness of dusts. Based on the experiments conducted, it was observed that the non-ferrous powder dust samples e.g. magnesium oxide, aluminium, aluminium oxide, zirconium oxide and copper oxide did not produced an ignition throughout the tests. Test carried out on zinc powder showed discoloration on the samples for the test using 12.5 mm thickness of dust layer. The hot-surface ignition temperature recorded was 206^{o}C. Tests carried out for iron powder also showed discoloration on the samples and the temperatures observed were approximately 177^{o}C and 236^{o}C for the sample thickness of 5 mm and 12.5 mm respectively. At the end of the paper, the minimum ignition energy will be determined for all dust samples. These findings would be useful to further understand the dust explosion mechanism and further improve the database of the ignition temperature and ignition energy for the samples tested.

ACKNOWLEDGEMENT

First and foremost, I would like to express my gratitude to God for His kind blessings by giving me strong will and determination to complete this Final Year Project (FYP) course. After all the difficulties and challenges for the past few months, this course was completed.

I would like to thank my supervisor, Dr. Azizul Buang for his expert guidance, continuous support and encouragement throughout the course of this research project. He has been a very supportive supervisor and willing to share his knowledge, in order to ensure that I could learn and understand every single thing in this project. My gratitude is also extended to FYP II coordinator, Dr. Abrar Inayat for his effort in assisting us in all the possible way.

Furthermore, I express my deepest gratitude to Universiti Teknologi PETRONAS (UTP) for the platform of my course. I am also grateful to Chemical Engineering Department of UTP for the support I received when undertaking the course work.

Finally, much love and thanks to my family and friends who has never failed in helping me through the thick and thin of time. It is the unfailing support from them that has enabled me to complete this FYP course. Not to forget those who are directly or indirectly involved in the completion of this project.

Thank you.

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
CSB	Chemical Safety and Hazard Investigation Board
FYP	Final Year Project
MIE	Minimum Ignition Energy
MIT	Minimum Ignition Temperature
MgSt	Magnesium Stearate
mm	Millimeter
NFPA	National Fire Protection Association
TGA	Thermogravimetric Analysis
UTP	Universiti Teknologi PETRONAS
ZnSt	Zinc Stearate

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 Background of Study

In the growth of technology processes in industry, hazards of dust fire and explosions are the risks in industry where dust layer or cloud could form during processes which are capable of ignition. The accumulation of a dust layer on the hot surface equipment can pose the fire and dust explosion. Based to the Chemical Safety Hazard Investigation Board (in USA), among 281 dust fire and explosion were identified in US industrial facilities from 1980 to 2005 (*Dust Explosion Hazards: Workstream 3 Proposal*, 2013).

There are several definitions of combustible dusts according to the National Fire Protection Association (NFPA). Referring to NFPA 654 is “a combustible articulate solid that presents a fire or deflagration hazard when suspended in air or some other oxidizing medium over a range of concentration, regardless of particle size or shape” ("Combustible Dust," 2013). From the previous edition of the NFPA Glossary, combustible dust was defined as “any finely divided solid material that is 420 microns or smaller in diameter, presents a fire or explosion hazard when dispersed in air”. Therefore, a combustible dust is any small material that has the ability to catch fire and explode when mixed with air. Combustible dust mostly comes from solid organic material such as sugar, flour, and wood; metals; and some nonmetallic inorganic materials. But all these materials can burn or explode when the particles are in the right size and concentration.

Based on the Chemical Safety Board (CSB) Report – US Dust Incident from 1980 to 2005, dust incidents are among the most significant industrial safety

problem. On average, there are ten dust explosion incidents happened per year. The incidents involved nearly five fatalities and 29 injuries per year. Moreover, the annual rate is increasing every year. Besides that, CSB Report also recorded that 281 incidents happened during that time. This incident involved 119 fatalities and 718 injuries. In 2003, the CSB launched investigations of three major industrial explosions involving combustible dusts powder. This explosion happened in North Carolina, Kentucky, and Indiana with the involvement of fourteen fatalities. Figure 1.1 and Figure 1.2 below show the type of dusts that are mostly found in incidents and industries involved in dust incidents. CSB chairman, Moure-Eraso said recently "when there are more accidents, there are more fatalities. And this process continues, and it seems to be never ending."

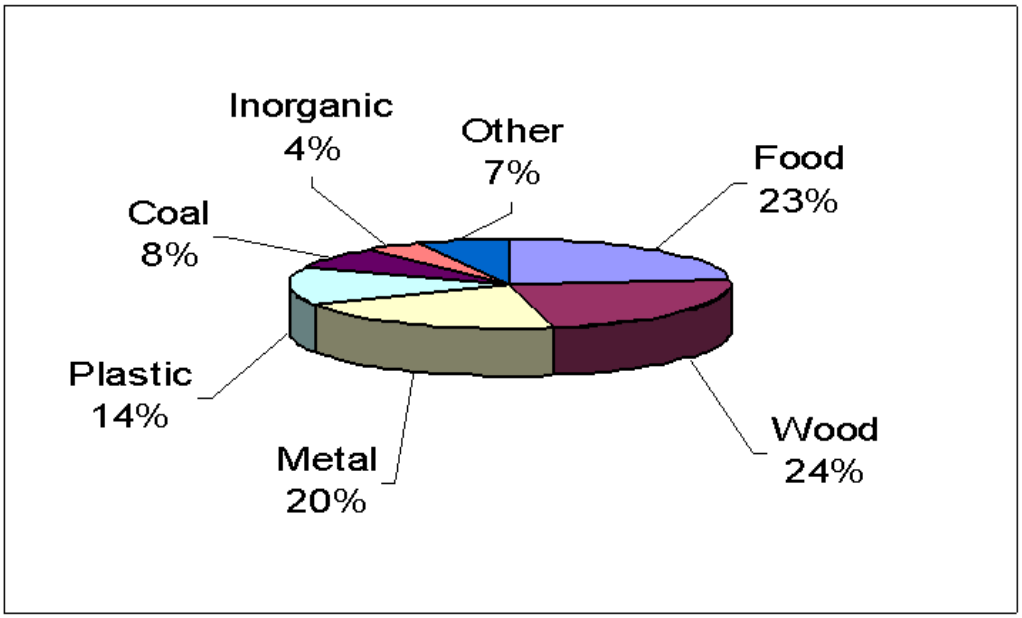


FIGURE 1.1 Type of Dusts Found in Incidents

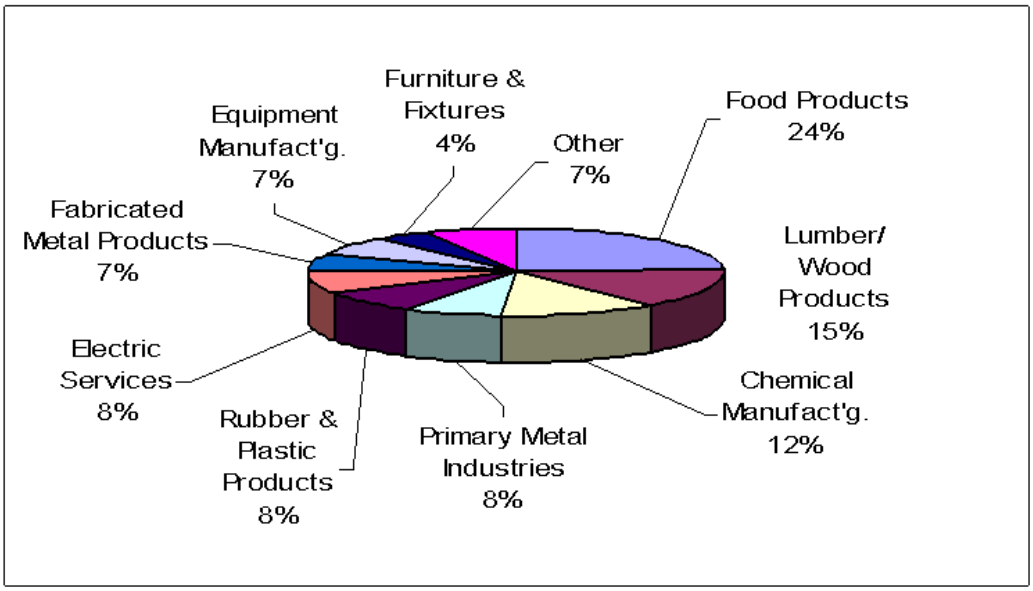


FIGURE 1.2 Industries Involved in Dusts Incidents

In industry, there are many materials that can be a combustible dust hazard for example in agricultural products (such as powder milk, sugar and flour), metals (such as aluminium, bronze, magnesium and zinc), chemical dust (such as coal and sulphur), rubber, wood and plastics. However, fire will be present with the presence of the three elements which are oxygen, fuel and ignition sources (also known as the "fire triangle"). For the occurrence of dust explosion, there are additional of other two elements, which are dispersion and confinement (also known as the "dust pentagon").

Therefore, the smaller particles of a flammable dust layer are capable of flammability and explosivity. In this project, it will discuss on the hot-surface requirement of ignition temperature of a dust layer of selected flammable dusts.

1.2 Problem Statement

On the early November 2010, the accident of an aluminium dust explosion occurred at a motorcycle rim manufacturing factory. The accident involved eight workers receiving injuries and two of them received serious injuries. The dust explosion also caused damage to building and manufacturing plant, the destruction of the dust collector system and also broke windows of factories nearby. Figure 1.3

below shows the damage on the system dust collector and the polishing machine which resulted in an ignition source for aluminium dust.

FIGURE 1.3 Part with Severe Damage on the System

From investigations carried out, an explosion occurs due to a small fire that originated from the polishing machine and then caused a chain of dust explosion to occur ("Combustible Dust Explosion at Motorcycle Rim Manufactured Factory," 2010).

In Malaysia, the real point of incidents ranging from grain dust (wheat, corn) to metallic (aluminium) and wood dusts that have occurred at regular intervals requires all engineering professionals to know all that needs to be known about the presence of combustible dusts that exist in the industrial environment (Chuan, 2014). Figure 1.4 shows a picture showing the effect of combustible dust explosion that happened in a factory in Penang involved in processing magnesium stearate (MgSt) and zinc stearate (ZnSt) materials. The explosion and ensuing fire caused widespread and heavy damage to the factory's processing plant with the loss of three lives and serious injuries of two workers.

FIGURE 1.4 Scene after Explosion and Fire in MgSt and ZnSt Processing Plant

Based to the theories of combustion as shown in Figure 2.1, combustion will occur when the fuel dust is exposed to heat in the presence of oxygen. However, for the dust explosion, it requires the presence of two other elements which are the particulate matter and the limited space (confinement). Suspended dust would easily burn very fast and limited space (confinement) will cause the production of high pressure within the shortest time. With the absence of one of the dust elements, which is the limited space (confinement), explosion can be avoided but fire can still occur.

Through this incident, it can be seen that the lack of knowledge among the workers about the combustible dust is the reason for the incident to happen. The knowledge on dust explosion phenomena and ways to control them is important to avoid this accident from happening again in the future. Fire and explosion can be avoided if one of the elements of fire and explosion properties is absent. In turn, the possibility of accidents to happen could be decreased. Therefore, the control of dust and ignition sources needs to be emphasized to prevent the accident.

Based on this recent accident, the student will conduct experiments to study on the minimum hot-surface ignition temperature of a dust layer of selected flammable dusts.

1.3 Objective

The main objective for this project is to conduct experimental analysis of hot-surface ignition temperature of a dust layer of selected dusts. Besides that, the minimum ignition energy (MIE) also will be calculated based on the minimum hot surface ignition temperature throughout the experiment.

1.4 Scope of Study

The parametric study of analysis minimal ignition temperature of a dust layer will focus on:

1. Type of flammable dust used.
2. Layer thickness of dust.

CHAPTER 2

LITERATURE REVIEW

Based on the article - '*minimum ignition temperature of a specific dust'* is defined as the minimum air temperature for which the flame due to combustion of the dust particle is just observed (Di Benedetto *et al.*, 2010). Other definition by Institut für Arbeitsschutz der DGUV, it is defined as the lowest temperature of a hot surface at which the flammable dust and air ignites under specific test condition ("Minimum ignition temperature of a dust cloud (ignition temperature)," 2013). However, the ignition temperature is capable for the present of the explosion characteristic. Figure 2.1 shows the element needed for the explosion properties.

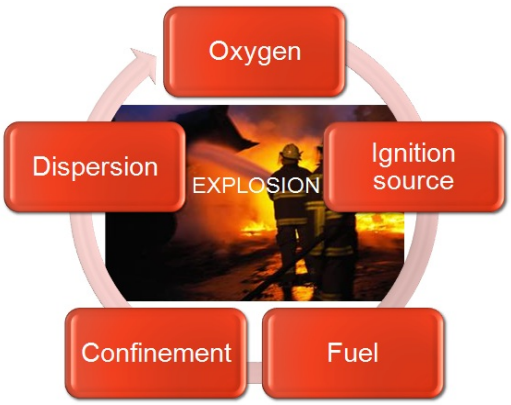


FIGURE 2.1 Explosion Properties

In industry, explosions are the biggest risk where the dust layer which one of the elements in the explosion properties forms during technology processes which is willing for ignition. The accumulated combustible dust will formed the dust layer on some hot process equipment such as dryer or hot bearing and result in explosion when the hot surface temperature is sufficiently high. Hot surface ignition

temperature of dust layers refers the minimum surface temperature which can ignite the certain thickness of dust layers.

Many materials can become combustible dust under specific situations. Table 2.1 shows the example of combustible dust in industry.

TABLE 2.1 Example of Dusts in Industry

Types	Example of Dusts
Agricultural Product	Corn star, wood flour, dry milk, sugar, wood flour, powered milk.
Agricultural Dusts	Cocoa powder, hops (malted), rice flour, wheat grain dust.
Carbonaceous Dusts	Petroleum coke, pine soot, bituminous coal, wood charcoal.
Chemical Dusts	Lactose, sulfur, calcium acetate, methyl-cellulose
Plastic Dusts	Phenolic resin, (poly) Propylene, (poly) vinyl chloride, melamine resin
Metal Dusts	Aluminium, magnesium, zinc, bronze

The oxygen content in air which is the second elements of explosion is all that is necessary to support an explosion. The presence of a flammable atmosphere does not solely constitute a hazard. An ignition source, which third element of explosion properties, which is sufficiently energetic to induce the combustion, is also required. There are two potential source of ignition as shown in Table 2.2 below.

TABLE 2.2 Source of Ignition

Ignition Source	Examples
Can be electrical	Static, lighting or generated
Can be mechanical	Match/lighter, spark and friction

Dispersion means the dust particles are suspended in air. Dispersion is one of the explosion properties which are willing of explosion when dispersion in the right

concentration. Confinement means the dust is in an enclosed or limited space. This restriction allows pressure to build up, increasing the likelihood of an explosion. Confinement can be provided by buildings, process equipment, dust collection equipment and ducting/piping.

According to the research papers about minimum ignition temperature of wood dust layer, there are several factors which easily affecting the ignition temperature of dust layer which are layer thickness and particle size of dust (Pastier *et al.*, 2013).

About the layer thickness, the thicker the layer dust, the lower the ignition temperature. So, when the dust layer thickness increase, the temperature gradient in the dust layer become smaller as well as reduces the conduction rate consequently. Next, for the particle size, the more complete oxidation occurred in smaller particle until a certain critical size. So, if the particle size is increase, the surface area is smaller and less rated combustion needed to overcome the rate of heat dissipation.

The study involved preparation of three samples dried and undried of wood dust layer for 5 mm and 12.5 mm from manufacture of wood which are:

1. Sample A – collected from cutting particleboard/fibreboard.
2. Sample B – collected from cutting poplar, spruce, alder and ash tree.
3. Sample C – collected from cutting chipboard.

Sieve analysis was performed before setting the minimum ignition temperature. From the experiment conducted, they got the highest minimum ignition temperature at 5 mm for sample A in undried state. For the lowest minimum ignition temperature was sample B in the dried and undried state. Table 2.3 below shows the result for the three samples in undried and dried state.

TABLE 2.3 Minimum Ignition Temperature of Wood Dust Layer

	Undried		Dried	
Layer	5 mm	12.5 mm	5 mm	12.5 mm
Sample	Minimum ignition temperature (°C)			
A	350	300	340	300
B	330	300	330	300
C	340	300	340	300

From the analysis, they concluded the minimal ignition temperature of flammable dust depends on the thickness of the dust layer. Even the minimum ignition temperature was measured for 12.5 mm layer; it was average lower by 50°C – 30°C than temperature for 5 mm layer of dust.

A study was also conducted to find the ignition temperature of dust layer and dust cloud of wood pellets (Horváth and Balog, 2013). In this experiment, two dust samples was prepared which are sample A is sample pellets made of softwood with bark and sample B is sample pellets made of softwood. Dust samples were prepared by grinding the pellets in a blender. Table 2.4 shows the percentage fractions sieving dust samples.

TABLE 2.4 Percentage Fractions Sieving Dust Samples

Sieve Size (µm)	**Percentage by Weight (%)**	
	Sample A	Sample B
> 500	56.98	39.51
500	24.98	27.5
250	3.72	5.88
200	4.42	7.37
150	5.05	8.94
90	1.65	2.2
< 71	3.76	8.11
The losses	0.45	0.49

From this experiment, the ignition time history of dust layer when tested on electrically heated plate was observed as shown in Figure 2.2.

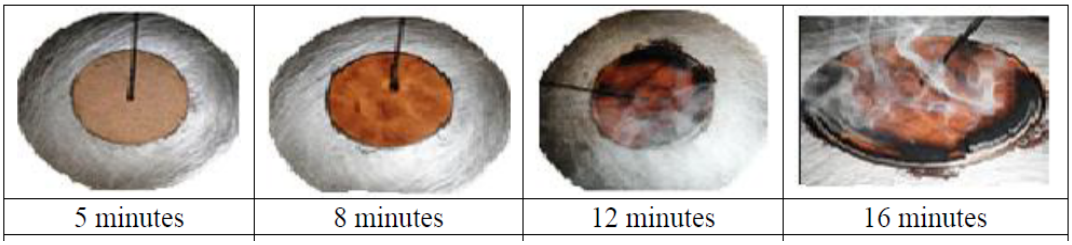


FIGURE 2.2 Ignition Time History of Dust Layer

Based on Figure 2.2, the observations made were as follow:

1. During the first five minutes, the location of the samples on a hot surface.
2. Temperature increase on the samples surface eight minutes later.
3. Smoldering on the sample surface and subsequent ignition happened twelve minutes later.
4. Smoldering and glowing samples take sixteen minutes to happen.

From the experiment conducted, they proved the minimum ignition temperature depends on the thickness of dust layer. The ignition temperature for sample A is 340°C for 5 mm and 310°C for 12 mm. However, for sample B, the ignition temperature for sample A is 350°C for 5 mm and 310°C for 12 mm. It has been found that with increase the thickness of dust layer, the ignition temperatures are reduced.

In another study, an experiment was conducted to study the minimum ignition temperature for layers of metal powder mixture. In their study, the dusts have been chosen based on two main criteria which are the minimum ignition temperature of dust must be significantly different and these materials must have distinct “thermal signatures” (strong exothermicity on a short period of time). The experiment has been carried out on a heating plate consisting on an Inconel square were put on plate of 280 mm length. Powder beds of 5 mm thickness were put on the plate and heated at a rate of 40°C/min to a maximum temperature of 480°C (Dufaud *et al.*, 2014).

The experiment was conducted by using various powders with a maximum diameter of 44 µm, which can be seen in Table 2.5. However, only zirconium and niobium powders ignited at a temperature closed to 300°C. It was then decided that powder having a lower particle size distribution (ranging from 1 to 6 µm) to be used. After the test, the result shown only four powders ignited which are iron, niobium, tantalum and zirconium.

TABLE 2.5 Characteristic of the Tested Metal Powders

Powders	Particle Size (µm)	Main Oxide	RPB (-)	$T_{ignition}$ (°C)	Observation	Providers
Aluminium	44	Al_2O_3	1.29	-	No ignition	Alfa Aesar
Iron	1 - 6	Fe_2O_3	2.14	155	Ignition	Goodfellow
Iron	44	Fe_2O_3	2.14	-	Self-heating	Sigma-Aldrich
Magnesium	44	MgO	0.80	-	No ignition	Alfa Aesar
Niobium	1 – 5	NbO	1.38	293	Ignition	Alfa Aesar
Niobium	44	NbO	1.38	304	Ignition	Alfa Aesar
Tantalum	2	Ta_2O_5	2.44	334	Ignition	Alfa Aesar
Tantalum	44	Ta_2O_5	2.44	-	Self-heating	Alfa Aesar
Titanium	44	TiO_2	1.78	-	No ignition	Alfa Aesar
Tungsten	44	WO_2	2.09	-	No ignition	Alfa Aesar
Zinc	44	ZnO	1.59	-	Self-heating	Merck
Zirconium	2 - 3	ZrO_2	1.55	181	Ignition	Alfa Aesar
Zirconium	44	ZrO_2	1.55	290	Ignition	Alfa Aesar

FIGURE 2.3 Ignition of a Fine Niobium Layer during Determination of Its Minimum Ignition Temperature

From another research focusing on the experimental analysis of minimal ignition temperature of a dust layer and clouds on a heated surface of selected flammable dusts are conducted. Tests have been performed for selected dusts: hop, lemon balm, nettle, senna fruit, valerian, buckwheat, barley, semolina, cornflakes, oatmeal, rice flakes, flour, malt, beech, dried carrot, corn starch and sunflower husk (Polka *et al.*, 2012).

The experiment was conducted in accordance with two methods. Based on Figure 2.4, Method A has been applied to determine minimum temperature at which the layer of dust located on a heated furnace plate undergo thermal decomposition or ignite. According to the procedure, the ignition of dust in the layer could be recognized when:

a) Glowing or flame combustion was observed as in Figure 2.5,
b) Measured temperature of dust have reached 450°C,
c) Measured temperature of dust exceeded by 250 K the temperature of the furnace plate.

In reference to point b) and c) the ignition of dust has not appeared if it could be indicated that oxidize reaction does not change into glowing or flame combustion process.

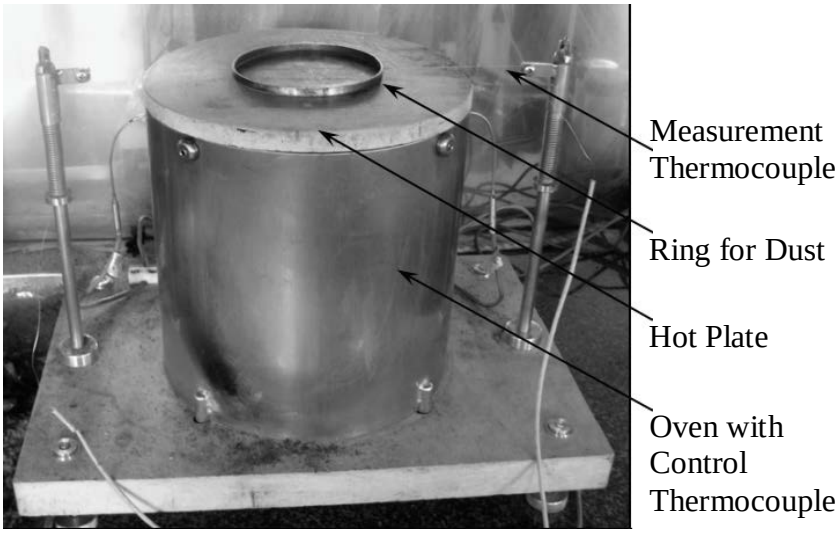


FIGURE 2.4 Apparatus Set-up for Method A

FIGURE 2.5 Observed Glowing of Sunflower Husk Dust

To define minimum ignition temperature of a dust cloud, Method B was applied as seen in Figure 2.6, in which a furnace with fixed temperature and testing equipment connected to it was applied.

FIGURE 2.6 Apparatus Set-up for Method B

From the experiment conducted, the result shows that the higher thickness of the dust layer causes a decrease of minimum ignition temperature (MIT). The Table 2.6 shows the MIT of chosen dusts.

TABLE 2.6 Minimum Ignition Temperature of Chosen Dusts

Dust	Parameters		
	Minimum Ignition Temperature of dust layer 5 mm	Minimum Ignition Temperature of dust layer 12,5 mm	Minimum Ignition Temperature of dust cloud
hop	290	280	460
lemon balm	290	260	480
nettle	290	260	500
senna fruit	300	270	520
valerian	280	250	520
buckwheat	320	290	450
barley	>400	400	450
semolina	>400	400	450
cornflakes	420	400	470
oatmeal	>400	>400	480
rice flakes	>400	>400	430
flour	420	400	-
malt	290	280	-
beech	320	280	-
dried carrot	300	-	580
corn starch	>400	-	460
sunflower hulls	290	-	460

Based on the critical literature review, the hot-surface ignition temperature of flammable dust may be affected by the thickness layer of the dusts. In addition, the particle size may also give effect to the ignition temperature of the dust. However, there is still no confirming data on this hypothesis.

CHAPTER 3

METHODOLOGY

3.1 Experiment Methodology

The methods to determine the hot-surface ignition temperature of dust are as follow:

1. The hot plate is kept at given temperature, which is read by the thermocouples and displayed on one of the recorder channel.
2. A metal ring, with a diameter of 100 mm and thickness 5 mm is laid on a surface of a hot plate.
3. The dust sample to be tested is placed in the metal ring and carefully leveled off to the height of the ring.
4. Thermocouple is placed in the sample through the holes in the metal ring to record the actual temperature of sample
5. The second thermocouple is used to control the hot plate temperature.
6. Temperature of ignition will be recorded based on physical observation. Example: The change of color or temperature in the dust layer rises at least 50°C above the hot plate temperature (*Referring to ASTM E2021-01*).
7. Repeat the experiment using the metal ring with a diameter of 100 mm and thickness 12.5 mm.

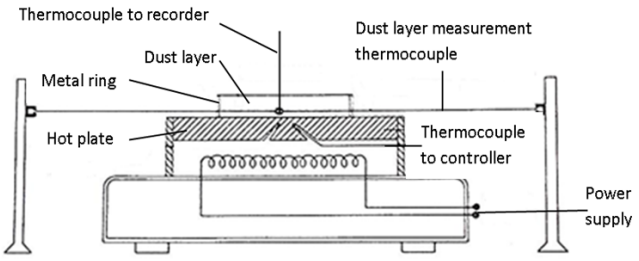


FIGURE 3.1 Apparatus Set-up for Hot Plate Test

From the hot-surface ignition temperature data collected, the minimum ignition energy will be calculated using the following formula:

$$Q = \mathrm{kA}\frac{\mathrm{dT}}{\mathrm{dx}} \tag{3.1}$$

Where:

Q = Rate of heat flow (W)

k = Thermal conductivity of material (W/m K) [k_{iron} = 79.5 and k_{zinc} = 116]

dT = Change in temperature of dust (min ignition temp – ignition temp),(K)

dx = Thickness of material (m)

After that, the experiment will be conducted and the hot-surface ignition temperature will be recorded for all the samples.

TABLE 3.1 Sample of Data Collection Table for Hot-Surface Ignition Temperature of 5 mm Thickness of Dust Layer

Types of Sample	**Ignition Temperature (°C)**	**MIE (kW)**
	T_{avg}	
Iron powder		
Zinc X		
Zinc Y		
Magnesium Oxide		
Aluminium powder		
Aluminium oxide		
Zirconium Oxide		
Copper Oxide		

TABLE 3.2 Sample of Data Collection Table for Hot-Surface Ignition Temperature of 12.5 mm Thickness of Dust Layer

Types of Sample	**Ignition Temperature (°C)**	**MIE (kW)**
	T_{avg}	
Iron powder		
Zinc X		
Zinc Y		
Magnesium oxide		
Aluminium powder		
Aluminium oxide		
Zirconium Oxide		
Copper Oxide		

TABLE 3.3 Sample of Data Collection Table for Mass Sample

Type of Sample	**Mass of Sample (g)**	
	Thickness of Dust Layer 5 mm	**Thickness of Dust Layer 12.5 mm**
	m_1	**m_1**
Iron powder		
Zinc X		
Zinc Y		
Magnesium oxide		
Aluminium powder		
Aluminium oxide		
Zirconium Oxide		
Copper Oxide		

3.2 Project Flow Chart

Below is the project flow chart for this study project that must be followed in order to achieve the objective of this study.

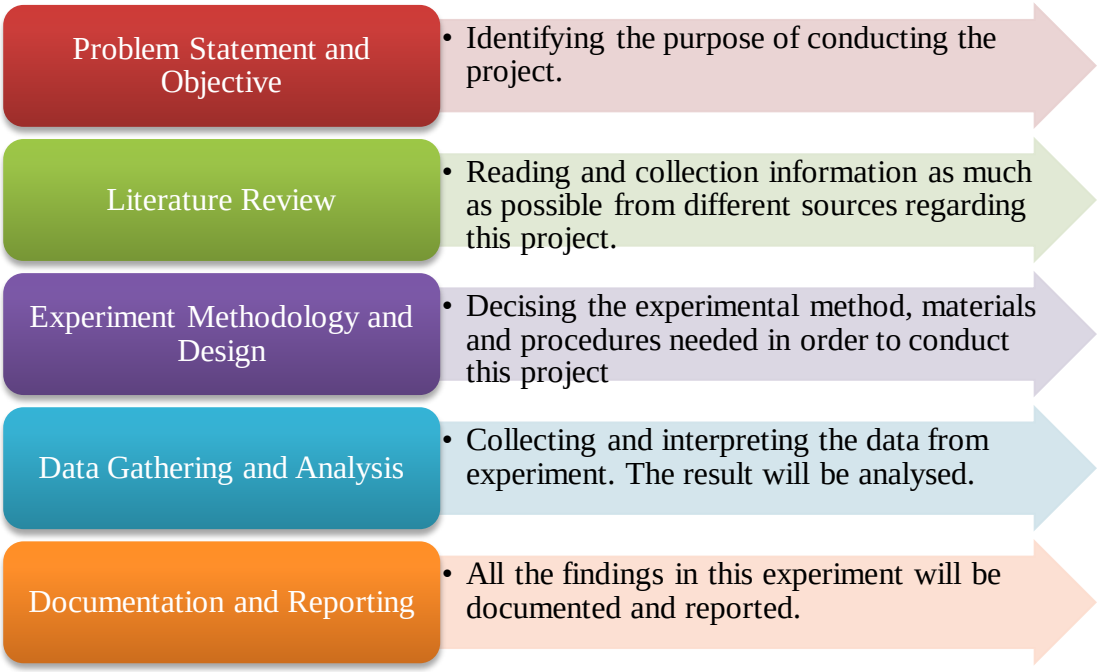


FIGURE 3.2 Project Flow Chart

3.3 Gantt Chart

Final Year Project I

TABLE 3.4 Final Year Project I Gantt Chart

NO	DETAILS	WEEKS													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Research title by supervisor														
2	Selection of project title														
3	Preliminary research work and proposal preparation														
4	Submission of extended proposal														
5	Proposal defense presentation														
6	Project work continues – to improve on all necessary elements														
7	Submission of Interim Draft Report														
8	Submission of Interim Report														

Process Suggested Milestone

Final Year Project II

TABLE 3.5 Final Year Project II Gantt Chart

NO	DETAILS	WEEKS													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Project work continues														
2	Submission of progress report														
3	Project work continues														
4	Pre-Sedex														
5	Submission of draft final report														
6	Submission of dissertation (soft bound)														
7	Submission of technical paper														
8	Viva														
9	Submission of project dissertation (hard bound)														

Process Suggested Milestone

CHAPTER 4

RESULT AND DISCUSSION

4.1 Data Table

After the experiments were conducted in testing the hot-surface ignition temperature of all samples, which are iron, zinc X, zinc Y, magnesium oxide, aluminium oxide, aluminium powder, copper oxide and zirconium oxide, the results were collected as shown in the table below.

TABLE 4.1 Data Collection Table for Hot-Surface Ignition Temperature of 5 mm Thickness of Dust Layer

Types of Sample	**Ignition Temperature (°C)**	**MIE (kW)**
	T_{avg}	
Iron powder	177	18.97
Zinc X	Non-ignition	T_{max} observed = 230
Zinc Y	Non-ignition	T_{max} observed = 440
Magnesium Oxide	Non-ignition	T_{max} observed = 131.1
Aluminium oxide	Non-ignition	T_{max} observed = 130.7
Aluminium powder	Non-ignition	T_{max} observed = 370
Zirconium Oxide	Non-ignition	T_{max} observed = 400
Copper Oxide	Non-ignition	T_{max} observed = 350

TABLE 4.2 Data Collection Table for Hot-Surface Ignition Temperature of 12.5 mm Thickness of Dust Layer

Types of Sample	**Ignition Temperature (°C)**	**MIE (kW)**
	T_{avg}	
Iron powder	236.9	10.58
Zinc X	206	13.19
Zinc Y	Non-ignition	T_{max} observed = 430°C
Magnesium oxide	Non-ignition	T_{max} observed = 100.2°C
Aluminium oxide	Non-ignition	T_{max} observed = 284.6°C
Aluminium powder	Non-ignition	T_{max} observed = 360°C
Zirconium Oxide	Non-ignition	T_{max} observed = 340°C
Copper Oxide	Non-ignition	T_{max} observed = 330°C

TABLE 4.3 Data Collection Table for Mass Sample

Type of Sample	**Mass of Sample (g)**	
	Thickness of Dust Layer 5 mm	**Thickness of Dust Layer 12.5 mm**
	m_1	**m_1**
Iron powder	63.268	120.3220
Zinc X	62.738	113.9026
Zinc Y	75.7269	280.3238
Magnesium oxide	35.5443	90.1213
Aluminium oxide	78.4273	185.2229
Aluminium powder	38.3532	92.429
Zirconium Oxide	110.1574	153.4135
Copper Oxide	59.9033	123.6036

4.2 Discussion

Based on the Figure 4.1 and Figure 4.2, it can be seen that the surface of iron powder started to change color for 5 mm and 12.5 mm thickness of dust layer.

FIGURE 4.1 Comparison of Iron Powder before (Left) and After (Right) the Experiment for 5 mm Thickness of Dust Layer

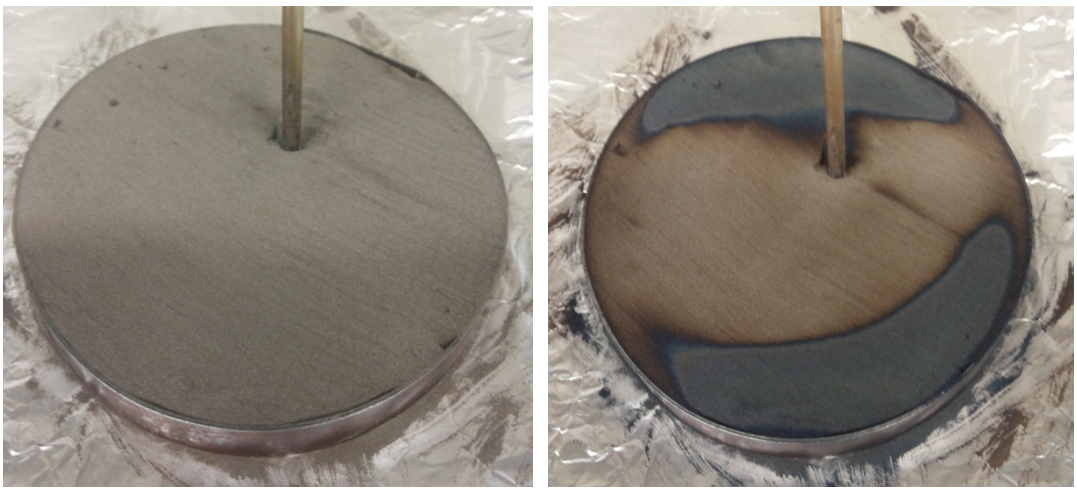


FIGURE 4.2 Comparison of Iron Powder before (Left) and After (Right) the Experiment for 12.5 mm Thickness of Dust Layer

Based on the data table, the graphs of temperature of dust layer vs. time were plotted for both 5 mm and 12.5 mm thickness of dust layer.

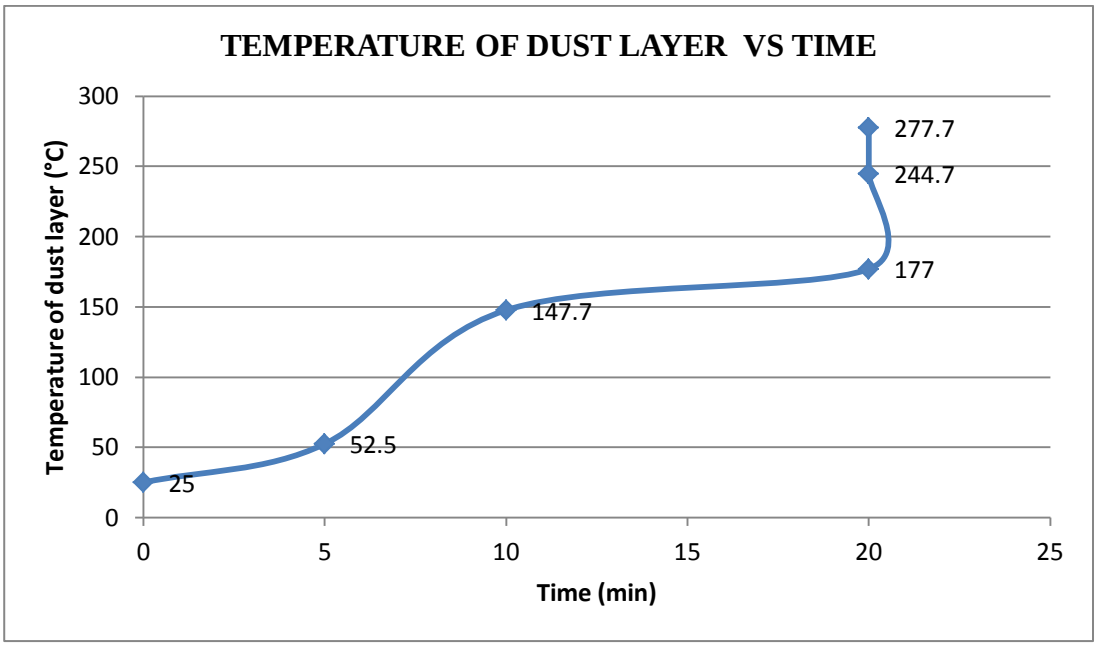


FIGURE 4.3 Graph of Temperature of Iron Powder Layer vs. Time for 5 mm Thickness of Dust Layer

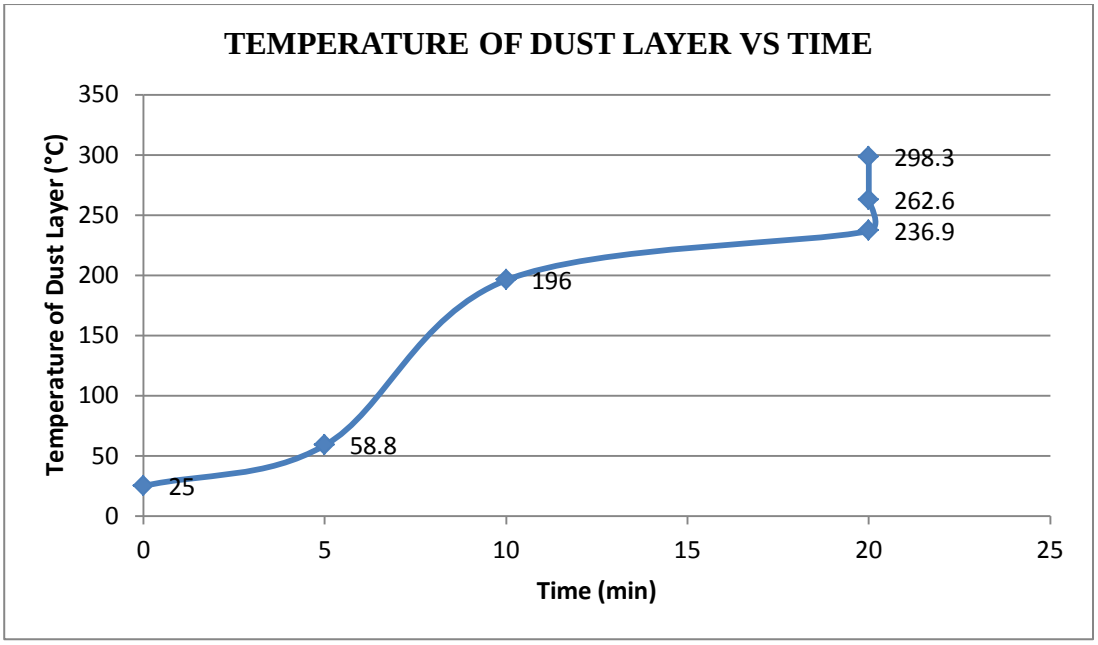


FIGURE 4.4 Graph of Temperature of Iron Powder Layer vs. Time for 12.5 mm Thickness of Dust Layer

Based on the graph plotted, it can be observed that the temperature of iron powder layer increases with time. When the surface of dust started to change, the temperature was recorded and considered as the hot-surface temperature for the particle to burn as shown in Figure 4.1 and Figure 4.2. Based on the graph plotted on Figure 4.3, the surface color of iron powder started to change after 20 minutes at 177°C. The temperature continuously increased until the surface of the powder changed color completely. The maximum temperature observed at 277.7°C. Referring to the graph in Figure 4.4, the surface color of iron powder started to change after 20 minutes at 236.9°C. The maximum temperature observed at 298.3°C.

By comparing both experiments of the thickness of iron powder layer, it can be observed that the thicker the layer is, the higher the ignition temperature. As a dust layer thickness increases, the accumulation temperature in the dust layer increases. The heat transfer, in which, energy exchange takes place from the region of high temperature (hot plate temperature) to the region of low temperature (surface of dust layer). When the amount of energy required was sufficient, the ignition happened. Therefore, it can be concluded that the thicker the layer is, the higher the ignition temperature.

Based on the Figure 4.5, the result shows that no changes on the surface of zinc X powder for 5 mm thickness of dust layer. For Figure 4.6, the result shows that the surface of zinc X powder started to change for 12.5 mm thickness of dust layer.

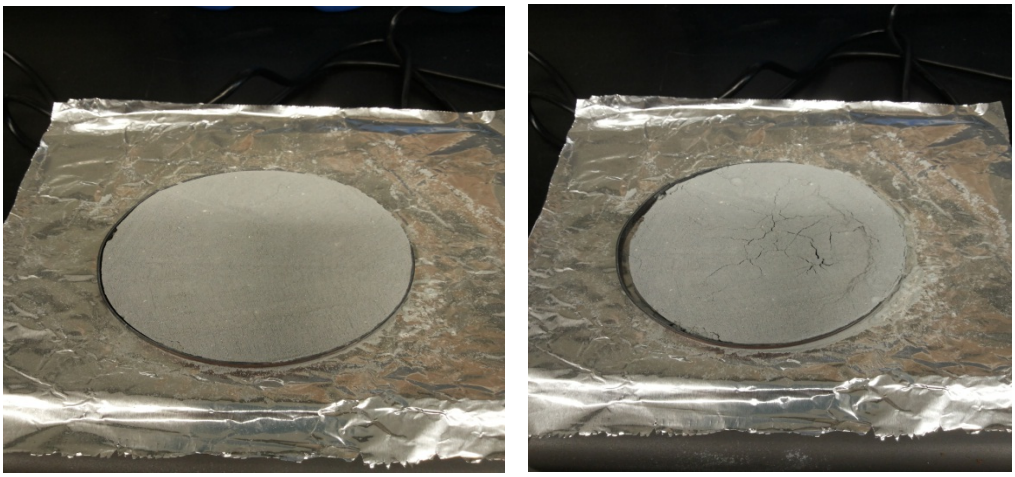


FIGURE 4.5 Comparison of Zinc X Powder before (Left) and After (Right) the Experiment for 5 mm Thickness of Dust Layer

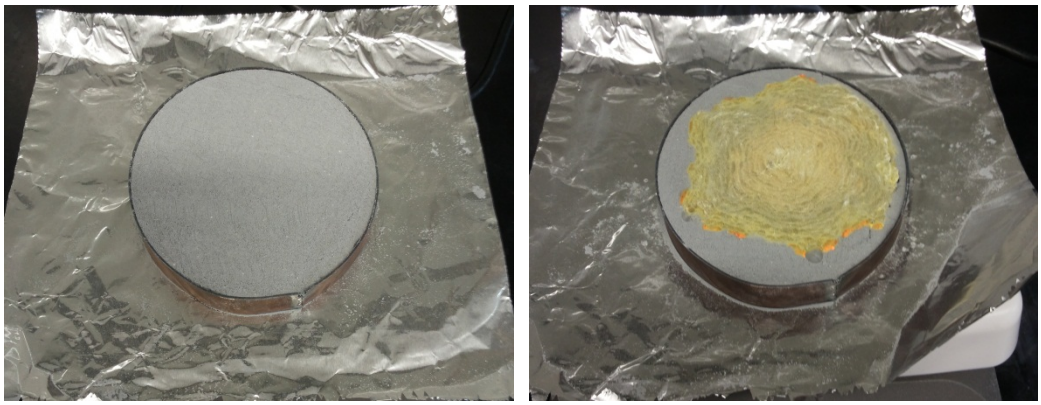


FIGURE 4.6 Comparison of Zinc X Powder before (Left) and After (Right) the Experiment for 12.5 mm Thickness of Dust Layer

Based on the data table, the graphs of temperature of dust layer vs. time were plotted for both 5 mm and 12.5 mm thickness of dust layer.

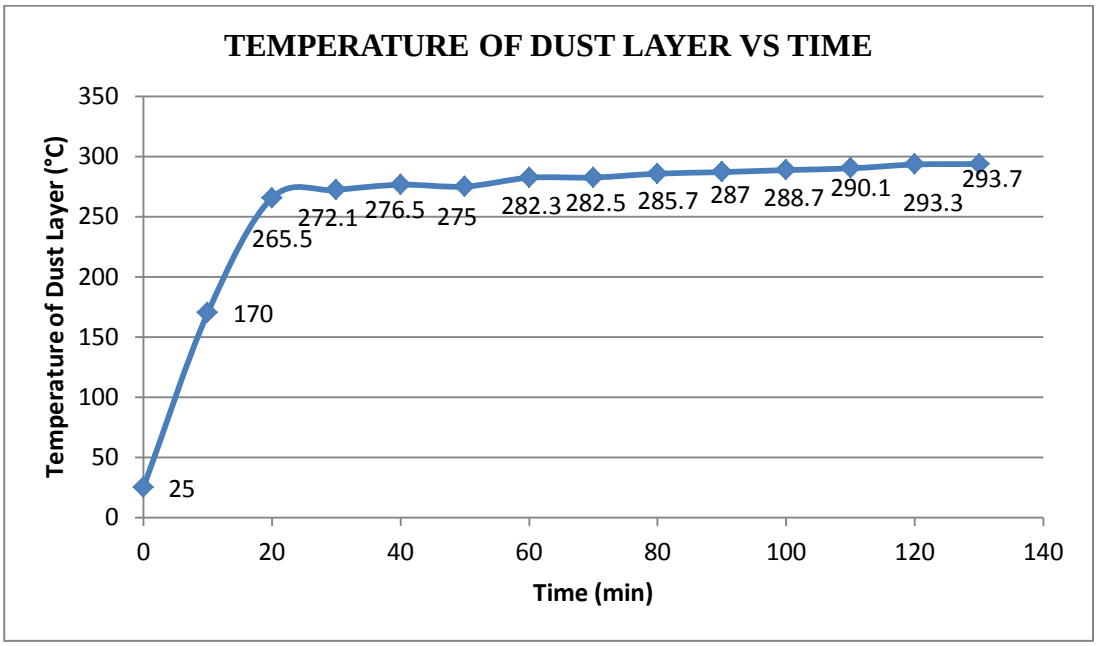


FIGURE 4.7 Graph of Temperature of Zinc X Powder Layer vs. Time for 5 mm Thickness of Dust Layer

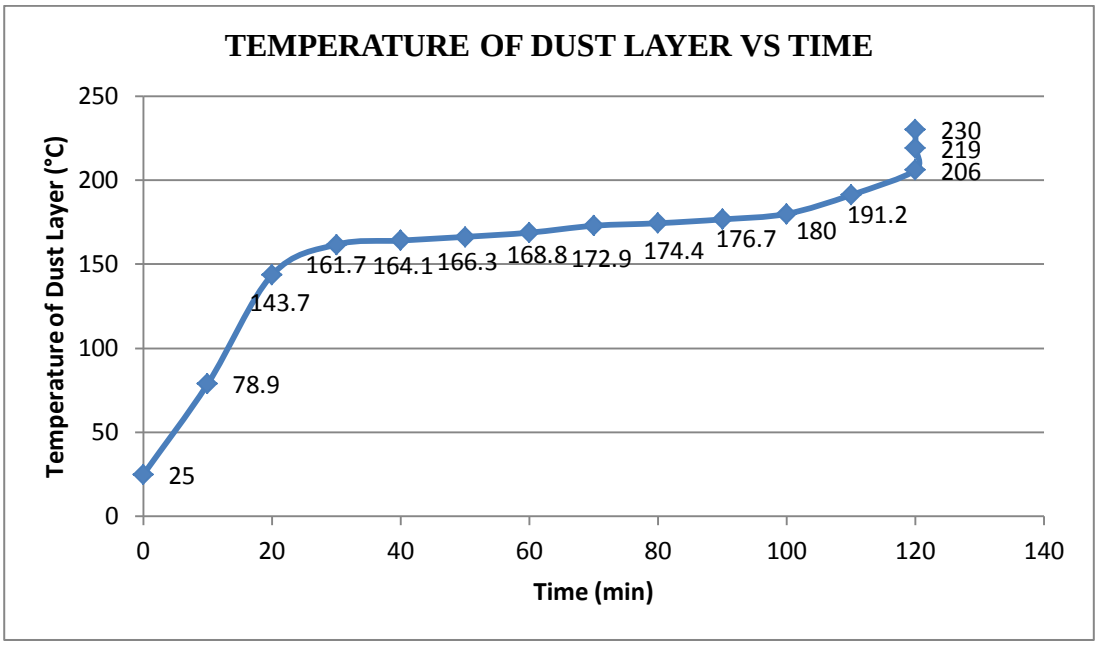


FIGURE 4.8 Graph of Temperature of Zinc X Powder Layer vs. Time for 12.5 mm Thickness of Dust Layer

Based on the graph plotted, it can be observed the temperature of zinc X powder layer increases with time. When the surface of dust started to change, the temperature was recorded and considered as hot-surface temperature for the particle to burn as shown in Figure 4.5 and Figure 4.6. Based on the graph plotted on Figure 4.7, there is some crack on the powder surface but no changes of color happened. That condition was considered as no ignition. Referring to the graph in Figure 4.8, the surface color of zinc X powder starts to change after 120 minutes at 206°C. The maximum temperature observed at 230°C.

By comparing both experiments of the thickness of zinc X powder layer, it can be observed that the thicker the layer is, the higher the ignition temperature. As a dust layer thickness increases, the accumulation temperature in the dust layer increases. The heat transfer, in which, energy exchange takes place from the region of high temperature (hot plate temperature) to the region of low temperature (surface of dust layer). When the amount of energy required was sufficient, the ignition happened. Therefore, it can be concluded that the thicker the layer is, the higher the ignition temperature.

However, the amount of energy required was not sufficient for 5 mm thickness of dust layer. Therefore, the ignition did not happen.

Based on the Figure 4.9 and Figure 4.10, the result shows that no changes on the surface of magnesium oxide powder for both 5 mm and 12.5 mm thickness of dust layer.

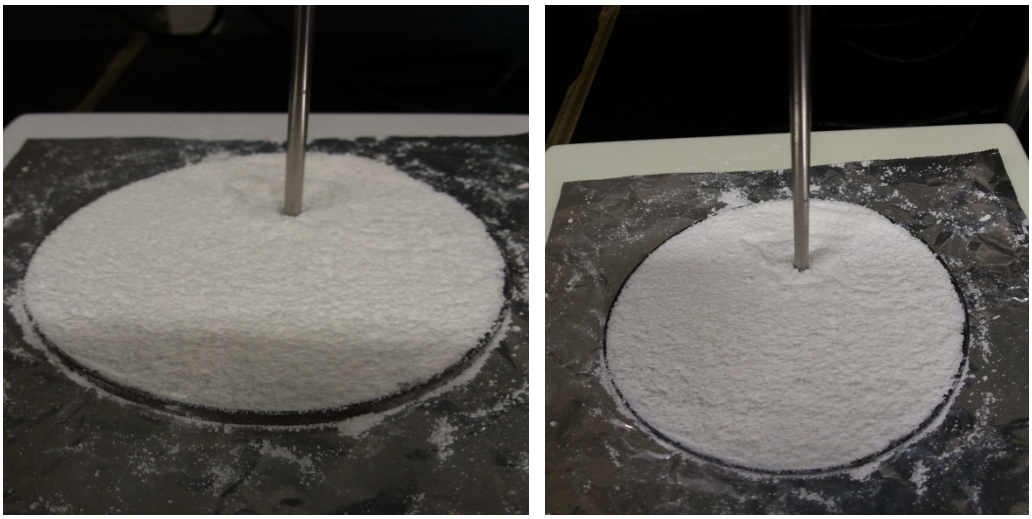


FIGURE 4.9 Comparison of Magnesium Oxide Powder before (Left) and After (Right) the Experiment for 5 mm Thickness of Dust Layer

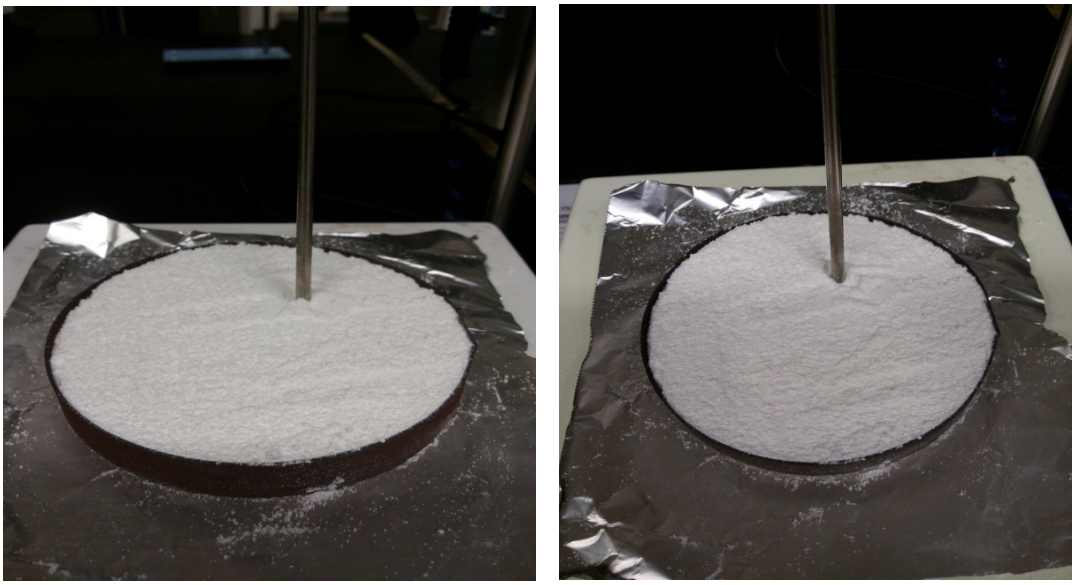


FIGURE 4.10 Comparison of Magnesium Oxide Powder before (Left) and After (Right) the Experiment for 12.5 mm Thickness of Dust Layer

Based on the data table, the graphs of temperature of dust layer vs. time were plotted for both 5 mm and 12.5 mm thickness of dust layer.

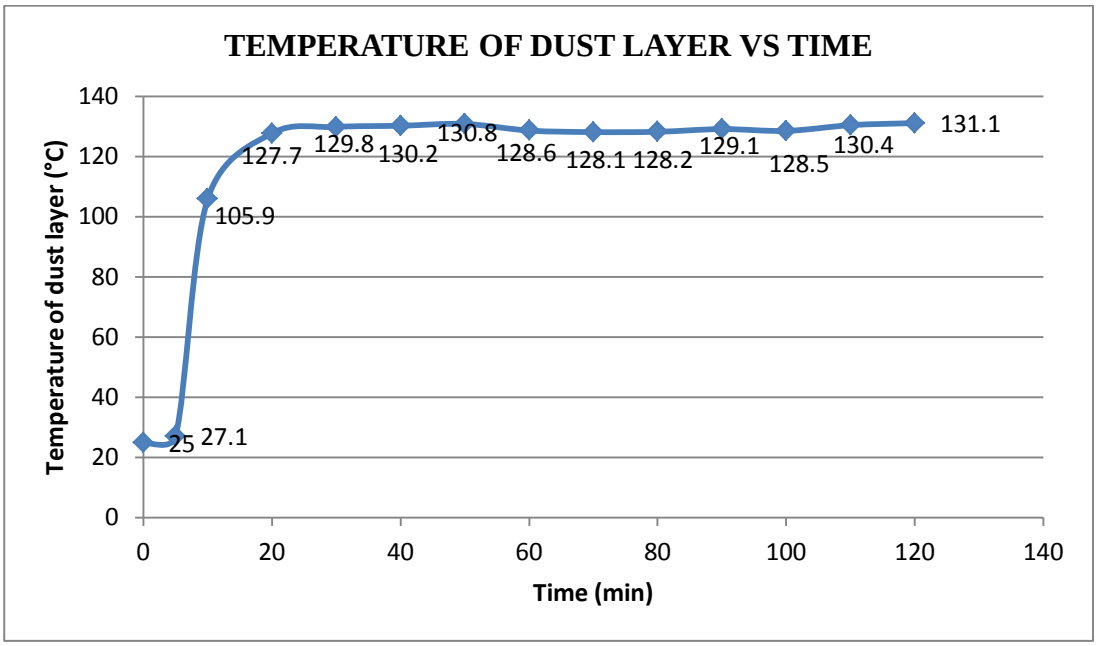


FIGURE 4.11 Graph of Temperature of Magnesium Oxide Powder Layer vs. Time for 5 mm Thickness of Dust Layer

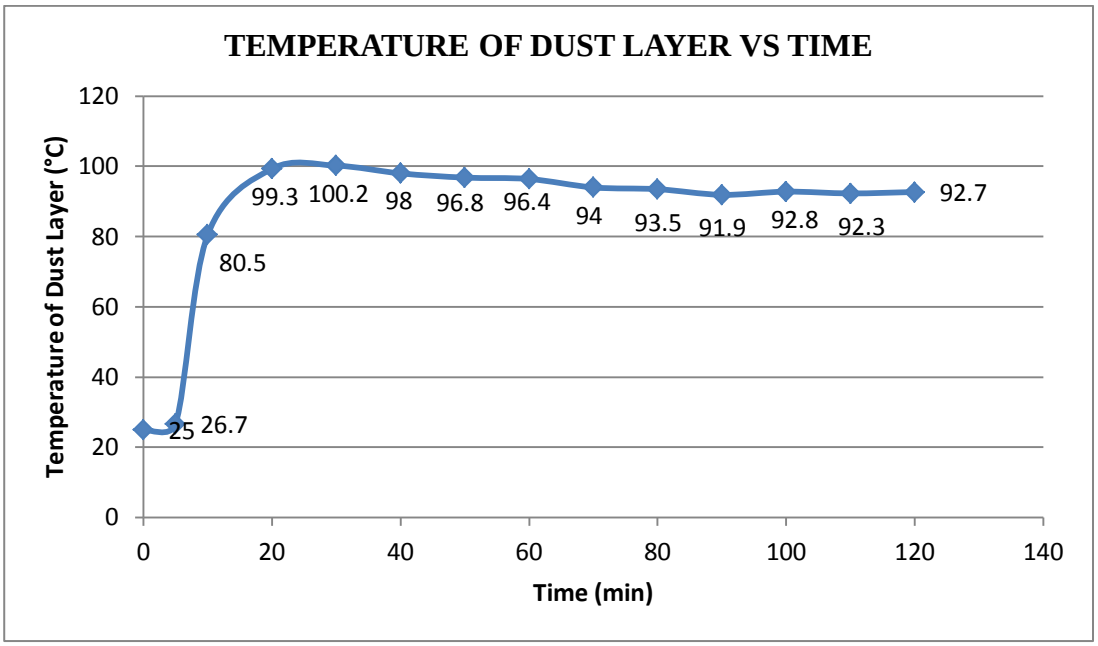


FIGURE 4.12 Graph of Temperature of Magnesium Oxide Powder Layer vs. Time for 12.5 mm Thickness of Dust Layer

Based on the graph plotted, it can be observed that the temperature of magnesium oxide powder layer increases with time. When the surface of dust started to change, the temperature was recorded and considered as hot-surface temperature for the particle to burn as shown in Figure 4.9 and Figure 4.10. Based on the graph plotted on Figure 4.11 and Figure 4.12, there were no color changes happened on both 5 mm and 12.5 mm thickness of dust layer. That condition was considered as no ignition. The maximum temperature observed for both thickness at 131.1°C and 92.7°C.

However, magnesium oxide is a non-ferrous metal (metals that do not contain iron). It has higher strength and melting point. Therefore, the electrostatic attraction between the particles is strong. It needs a lot of energy to overcome this attraction.

Hence, the amount of energy required was not sufficient for magnesium oxide powder for both 5 mm and 12.5 mm thickness of dust layer. Therefore, the ignition did not happen.

Based on the Figure 4.13 and Figure 4.14, the result shows that no changes on the surface of aluminium oxide powder for both 5 mm and 12.5 mm thickness of dust layer.

FIGURE 4.13 Comparison of Aluminium Oxide Powder before (Left) and After (Right) the Experiment for 5 mm Thickness of Dust Layer

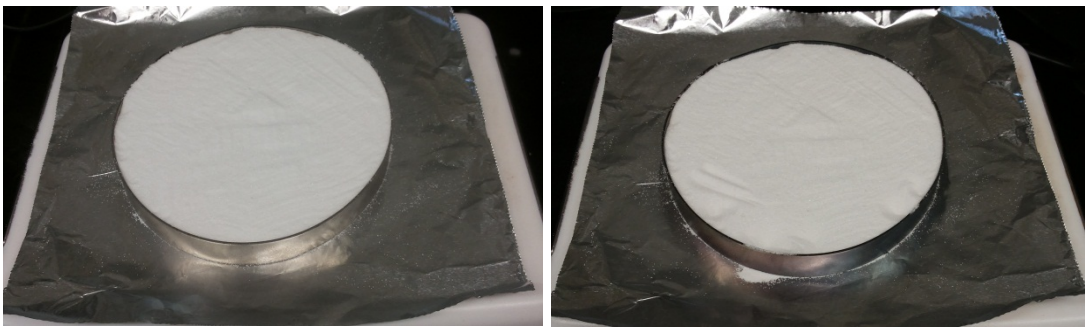


FIGURE 4.14 Comparison of Aluminium Oxide Powder before (Left) and After (Right) the Experiment for 12.5 mm Thickness of Dust Layer

Based on the data table, the graphs of temperature of dust layer vs. time were plotted for both 5 mm and 12.5 mm thickness of dust layer.

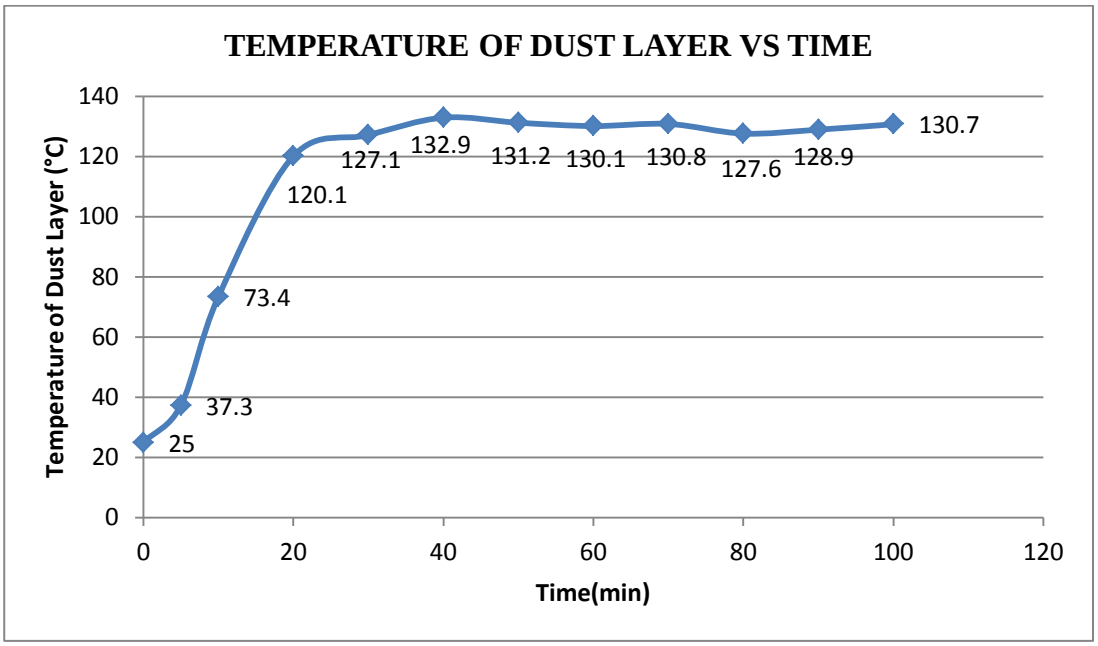


FIGURE 4.15 Graph of Temperature of Aluminium Oxide Powder Layer vs. Time for 5 mm Thickness of Dust Layer

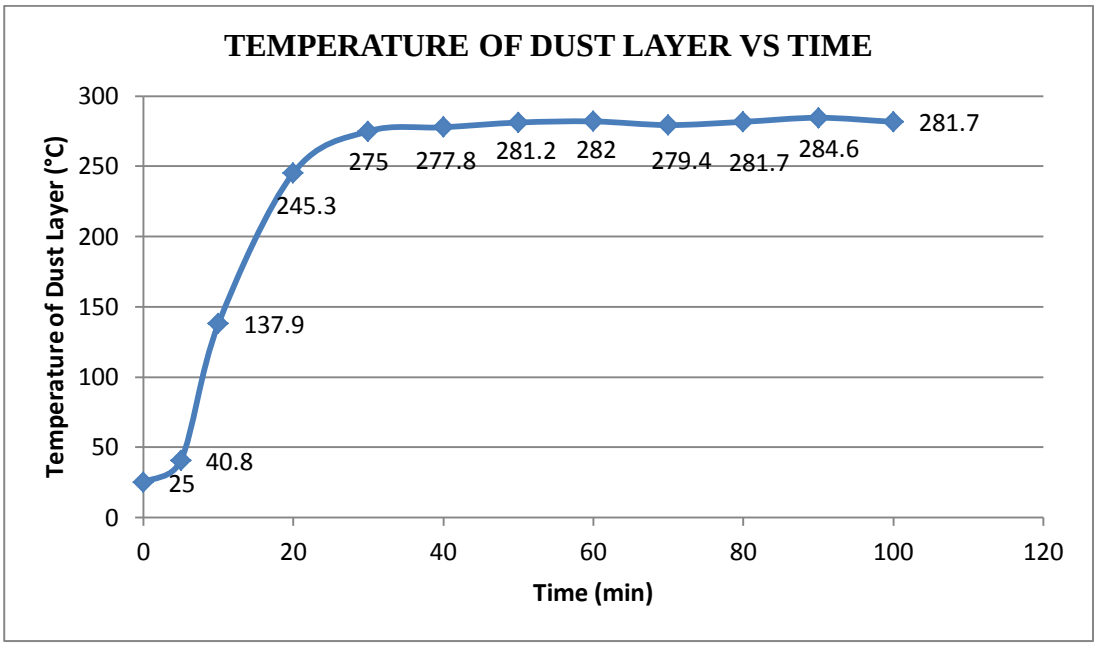


FIGURE 4.16 Graph of Temperature of Aluminium Oxide Powder Layer vs. Time for 12.5 mm Thickness of Dust Layer

Based on the graph plotted, it can be observed the temperature of aluminium oxide powder layer increases with time. When the surface of dust started to change, the temperature was recorded and considered as hot-surface temperature for the particle to burn as shown in Figure 4.13 and Figure 4.14. Based on the graph plotted on Figure 4.15 and Figure 4.16, there were no color changes happened on both 5 mm and 12.5 mm thickness of dust layer. That condition was considered as no ignition. The maximum temperature observed for both thickness at 130.7°C and 281.7°C.

However, aluminium oxide is a non-ferrous metal (metals that do not contain iron). It has higher strength and melting point. Therefore, the electrostatic attraction between the particles is strong. It needs a lot of energy to overcome this attraction.

Hence, the amount of energy required was not sufficient for aluminium oxide powder for both 5 mm and 12.5 mm thickness of dust layer. Therefore, the ignition did not happen.

From the experiment conducted on the aluminium powder, the surface of dust started to change as the temperature increased. When the surface of dust started to change, the temperature was recorded and considered as hot-surface temperature for the particle to burn as shown in Figure 4.17 and Figure 4.18. Based on the Figure 4.17 and Figure 4.18, the results show that no changes on the surface of aluminium powder for both 5 mm and 12.5 mm thickness of dust layer. That condition was considered as no ignition. The maximum temperature observed for both thickness at 370°C and 360°C.

However, aluminium powder is a non-ferrous metal (metals that do not contain iron). It has higher strength and melting point. Therefore, the electrostatic attraction between the particles is strong. It needs a lot of energy to overcome this attraction. Hence, the amount of energy required was not sufficient for aluminium powder for both 5 mm and 12.5 mm thickness of dust layer. Therefore, the ignition did not happen.

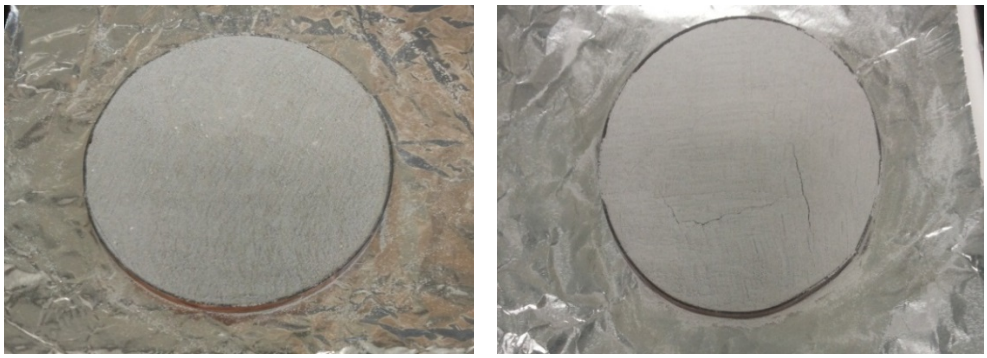


FIGURE 4.17 Comparison of Aluminium Powder before (Left) and After (Right) the Experiment for 5 mm Thickness of Dust Layer

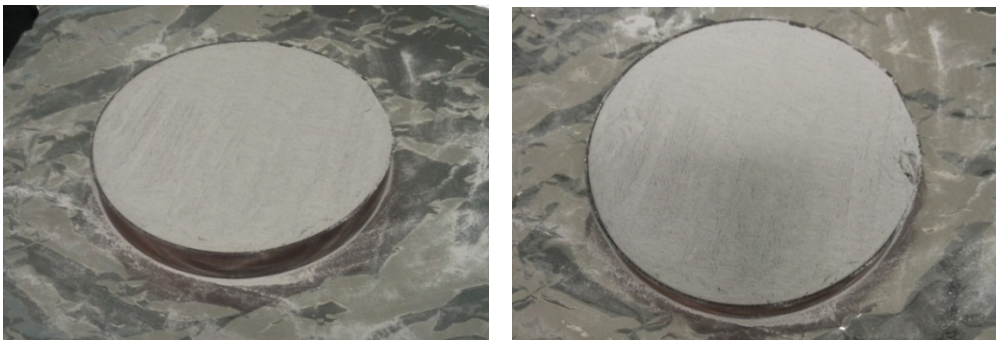


FIGURE 4.18 Comparison of Aluminium Powder before (Left) and After (Right) the Experiment for 12.5 mm Thickness of Dust Layer

From the experiment conducted on the zinc Y powder, the surface of dust started to change as the temperature increased. When the surface of dust started to change, the temperature was recorded and considered as hot-surface temperature for the particle to burn as shown in Figure 4.19 and Figure 4.20. Based on the Figure 4.19 and Figure 4.20, the results show that no changes on the surface of zinc Y for both 5 mm and 12.5 mm thickness of dust layer. That condition was considered as no ignition. The maximum temperature observed for both thickness at 440°C and 430°C.

The heat transfer, in which, energy exchange takes place from the region of high temperature (hot plate temperature) to the region of low temperature (surface of dust layer). When the amount of energy required was sufficient, the ignition happened. Therefore, the amount of energy required was not sufficient for 5 mm and 12.5 mm of dust layer. Therefore, the ignition did not happen.

FIGURE 4.19 Comparison of Zinc Y Powder before (Left) and After (Right) the Experiment for 5 mm Thickness of Dust Layer

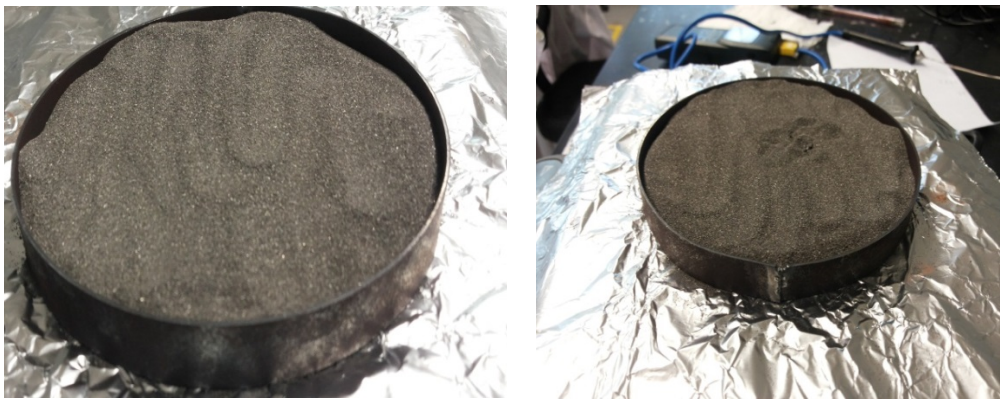


FIGURE 4.20 Comparison of Zinc Y Powder before (Left) and After (Right) the Experiment for 12.5 mm Thickness of Dust Layer

From the experiment conducted on the zirconium oxide powder, the surface of dust started to change as the temperature increased. When the surface of dust started to change, the temperature was recorded and considered as hot-surface temperature for the particle to burn as shown in Figure 4.21 and Figure 4.22. Based on the Figure 4.21 and Figure 4.22, the results show that no changes on the surface of zirconium oxide powder for both 5 mm and 12.5 mm thickness of dust layer. That condition was considered as no ignition. The maximum temperature observed for both thickness at 400°C and 340°C.

However, zirconium oxide powder is a non-ferrous metal (metals that do not contain iron). It has higher strength and melting point. Therefore, the electrostatic attraction between the particles is strong. It needs a lot of energy to overcome this attraction. Hence, the amount of energy required was not sufficient for zirconium oxide powder for both 5 mm and 12.5 mm thickness of dust layer. Therefore, the ignition did not happen.

FIGURE 4.21 Comparison of Zirconium Oxide Powder before (Left) and After (Right) the Experiment for 5 mm Thickness of Dust Layer

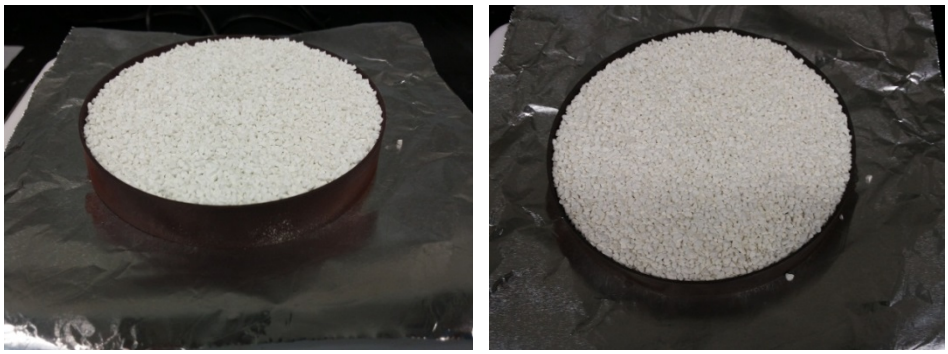


FIGURE 4.22 Comparison of Zirconium Oxide Powder before (Left) and After (Right) the Experiment for 12.5 mm Thickness of Dust Layer

From the experiment conducted on the copper oxide powder, the surface of dust started to change as the temperature increased. When the surface of dust started to change, the temperature was recorded and considered as hot-surface temperature for the particle to burn as shown in Figure 4.23 and Figure 4.24. Based on Figures 4.23 and Figure 4.24, the results show that no changes on the surface of zirconium oxide powder for both 5 mm and 12.5 mm thickness of dust layer. That condition was considered as no ignition. The maximum temperature observed for both thickness at 350°C and 330°C.

However, copper oxide powder is a non-ferrous metal (metals that do not contain iron). It has higher strength and melting point. Therefore, the electrostatic attraction between the particles is strong. It needs a lot of energy to overcome this attraction. Hence, the amount of energy required was not sufficient for copper oxide powder for both 5 mm and 12.5 mm thickness of dust layer. Therefore, the ignition did not happen.

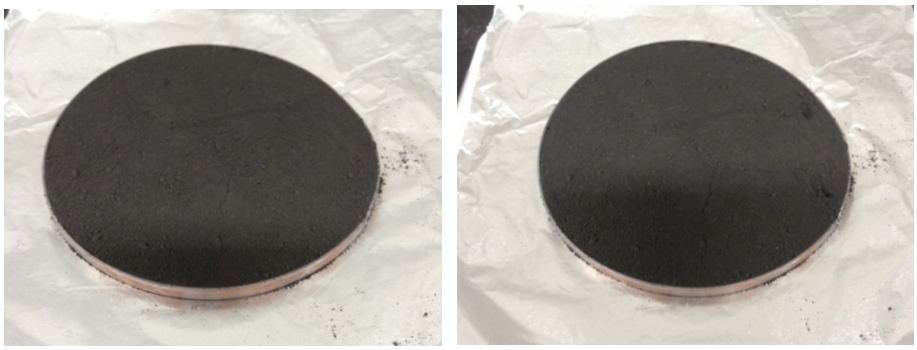


FIGURE 4.23 Comparison of Copper Oxide Powder before (Left) and After (Right) the Experiment for 5 mm Thickness of Dust Layer

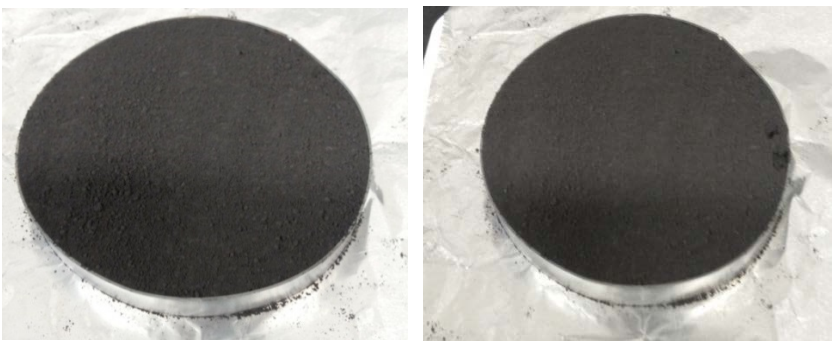
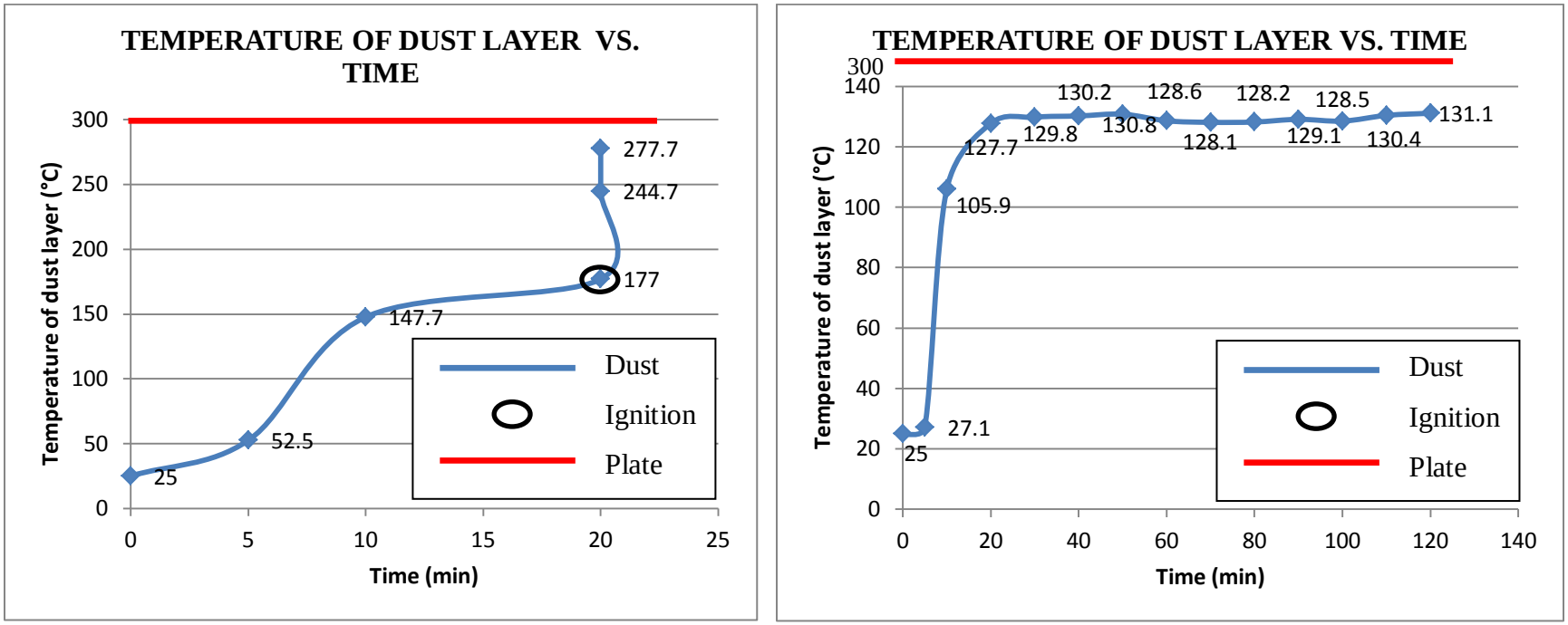


FIGURE 4.24 Comparison of Copper Oxide Powder before (Left) and After (Right) the Experiment for 12.5 mm Thickness of Dust Layer

4.3 Comparing Graphs between Ignition and Non-Ignition



(a) (b)

FIGURE 4.25 Change of Temperature of Iron and Magnesium Oxide Powder in 5 mm Thickness of Dust Layer (a) with Ignition at 177°C, and (b) without Ignition at T_{max} Observed 131.1°C

Based on the graphs plotted on Figure 4.25, it can be observed that the temperature of iron and magnesium powder layer increases with time. In order to determine the hot-surface ignition temperature of dust powder, the temperature was recorded with regard to two main criteria:

1. The change of color on the surface of dust sample
2. Temperature in the dust layer rises at least 50°C above the hot plate temperature *(Referring to ASTM E2021-01)*

Based on Figure 4.25(a), the temperature started to rise gradually as the surface color of iron powder started to change after 20 minutes at 177℃. Therefore, the temperature was recorded and considered as the hot-surface temperature for the particle to burn. It can be concluded that ignition happened.

Compared to the graph plotted on Figure 4.25(b), the temperature rose in the first 20 minutes. After that, there are no significant changes on the temperature. The temperature in the dust layer was still lower than the hot plate temperature. Additionally, based on the observation, there was no color change happened on the surface of magnesium oxide powder. It can be concluded that ignition did not happen.

4.4 Determination of MIE

From the data collected, the minimum ignition energy will be calculated using Equation (3.1):

Calculation MIE for Iron Powder of 5 mm Thickness of Dust Layer

K_{iron} = 79.5 W/m K

A = 0.00785 m²

dT = [(177 + 273) – 298] = 152 K

dx = 0.005 m

$$Q = (79.5)(0.00785)\frac{152}{0.005}$$

= 18.97 kW

Calculation MIE for Iron Powder of 12.5 mm Thickness of Dust Layer

K_{iron} = 79.5 W/m K

A = 0.00785 m²

dT = [(236.9 + 273) – 298] = 211.9 K

dx = 0.0125 m

$$Q = (79.5)(0.00785)\frac{211.9}{0.0125}$$

= 10.58 kW

Calculation MIE for Zinc Powder of 12.5 mm Thickness of Dust Layer

K_{zinc} = 116 W/m K

A = 0.00785 m²

dT = [(206 + 273) – 298] = 181 K

dx = 0.0125 m

$$Q = (116)(0.00785)\frac{181}{0.0125}$$

= 13.19 kW

CHAPTER 5

CONCLUSION

In conclusion, hopefully this project will give human more awareness towards the fire and explosion hazard in the workplace. By studying minimum ignition temperature of flammable dust, more cautions and safety role toward the fire and explosion hazard can be taken especially in industry production as well as reducing the potential of fire and explosion hazard incident in manufacturing facilities.

In addition, this project is feasible by taking into account the time constraint and the capability of final year student in finishing the project with the assistance from the supervisor and coordinator. It is a big hope for the accomplishment of this study. In future, it is recommended to identify the particle size of the sample. If the particle size is bigger, the surface area and rate of combustion are too small to overcome the rate of heat dissipation. Hence different particle sizes might affect the hot surface ignition temperature. Thus, this step is highly recommended. Apart from that, for future study, it is also recommended to run this experiment by using other techniques, such as Thermogravimetric Analysis (TGA).

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